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Supply chain and logistics issues of bio-energy production

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ABSTRACT

Within the concert of renewable energy technologies, bio-energy can play a decisive role during the next decades, when smartly designed and applied under favorable conditions. In this respect, efficient and effective supply chain and logistics management represent one key parameter. This paper presents a literature review of articles published in English-speaking peer-reviewed journals from 2000 to 2009, which cover the interface of bio-energy production and issues of logistics and supply chain management. First, the articles are assessed according to descriptive criteria such as journal, year of publication and research design applied. Then, issues and challenges of designing and operating biomass chains that secure stable and competitively-priced feedstock supply for bio-energy plants have been classified (1) into the operations harvesting and collection, storage, transport, and pre-treatment techniques as well as (2) into overall supply system design. Although biomass supply chains for energy use are manifold in terms of size, design, and functioning, most relevant issues regarding supply chain management and logistics of bio-energy production are identified. The findings are discussed against the backdrop of bio-energy as sustainable renewable energy option.

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1. Introduction

Bio-energy as sustainable renewable energy option attracts many hopes. Mainly, bio-energy is assumed to reduce CO_2-emissions (Nguyen et al., 2010), to preserve non-renewable resources, to enhance energy security, and to promote regional development (Ecosense, 2007) and rural diversification by creating jobs and income in usually underdeveloped rural areas (Elghali et al., 2007). On the other hand, critical voices pointing to the adverse sustainability balance of certain forms of bio-energy from a whole life-cycle perspective have become ever louder on the academic and public stage in recent years.

Bio-ethanol production is one example of such a contentious bio-energy form. Puppan (2002) comes to the conclusion that the environmental life-cycle balance of bio-diesel and ethanol is much more favorable than those of fossil fuels, if the agricultural climate conditions are advantageous. In contrast, a review of studies comparing bio-ethanol systems to conventional fuels on a life-cycle basis conducted by von Blottnitz and Curran (2007) reaches the conclusion that the balance of environmental impacts of current liquid fuels from biomass is ambiguous. Apart from the definite advantage of bio-fuels to reduce resource use, their impacts, e.g. on acidification, human and ecological toxicity and eutrophication, have been evaluated more often unfavorably than favorably (von Blottnitz and Curran, 2007). Moreover, energy efficiency of bio-fuels varies strongly according to plant species, climate, and production technique: Bio-ethanol from Brazilian sugar cane yields 8 units bio-energy output from one unit fossil fuel input into the production process. Biodiesel produced from rapeseed in the EU has a ratio of 1:2.5, while bio-ethanol from US corn merely holds an efficiency of 1:1.5 (GTZ, 2006).

Apart from these environmental and efficiency issues illustrated above, there are major additional problems linked to bio-energy, of which only some can be mentioned in the framework of this paper: Challenges arise from competing land use between biomass production for food, material and energy use. This competition has most serious repercussions primarily in developing countries (Kerckow, 2007). In these regions, food shortages may be reinforced, together with fuel poverty, since the cultivated energy crops represent commodities to be exported to the industrialized world. In addition, water shortage may be severely aggravated in susceptible regions by the cultivation of energy crops (Gerbens-Leenes et al., 2009). Moreover, conversion of former grasslands or woodlands into agricultural lands used for the production of energy crops or into forest monocultures may release great amounts of greenhouse gas. In this respect, one extreme example is the conversion of tropical and subtropical rain forests into oil palm monocultures in South Asia (Reijnders and Huijbregts, 2008; Reinhard and Zah, 2009), which, in addition, harms irreversibly

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the sensitive soil and may lead to desertification in the long run (WBGU, 2009).

When evaluating bio-energy production, a system perspective has to be taken encompassing the components biomass resources, supply systems, conversion technologies, and energy services. In practice many idiosyncratic combinations of these components are possible, which makes direct comparisons between different bio-energy systems difficult (McComick and Kåberger, 2007). Still, it is obvious that providing economically, environmentally and socially sustainable bio-energy requires an optimization of the structure and functioning of the supply chain/network, adjusted to the specific conditions of the respective production system (climate and topology, feedstock, technologies, final application). In terms of activities, harvesting, refining and transporting of biomass are key issues, which must be facilitated by supply chain and operations management as well as the adoption of most adequate technologies (McComick and Kåberger, 2007).

These considerations confirm the high relevance of supply chain and logistics issues for the implementation of bio-energy production systems and hence make this topic a suitable subject for a research literature review. The extant paper reviews and assesses systematically all papers dealing with this subject, published in English-speaking peer-reviewed journals from 2000 to 2009. The aim of the paper is structuring supply chain management (SCM) and logistics issues of bio-energy production.

The structure of the paper is as follows: after defining basic terminology, the methodology of the literature review is outlined. After a descriptive analysis of main features of the paper sample, issues and challenges of designing and operating biomass supply chains for energy use are assessed by a systematic review. Subsequently the findings are briefly discussed against the backdrop of bio-energy as sustainable renewable energy option.

2. Sustainability, bio-energy, logistics management and supply chain management – terms and definitions

The Brundtland Commission shaped one of the most well-known definitions of sustainability, highlighting the equal right of present and future generations to meet their respective needs (WCED, 1987). Elkington (1997) posits the integration of the intensely interrelated economic, ecological and social aspects of sustainability in a "triple-bottom line". Also Dyllick and Hockerts (2002) point to the three facets of sustainability, conceiving corporate sustainability as the business case (economic), the natural case (environmental), and the societal case (social).

Biomass for bio-energy comprises wood, agricultural and forestry residues, energy crops, human and animal excrement as well as industrial and municipal bio-degradable waste (Allen et al., 1998). Bio-fuels are solid, liquid, and gaseous fuels based on biomass. Bio-energy is defined as energy (heat, electricity, mobility) from bio-fuels (McComick and Kåberger, 2005).

The Council of Supply Chain Management Professionals (CSCMP) defines logistics management as "that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements" (CSCMP, n.d.).

Mentzer et al. (2001) coined commonly used and well-adopted definitions of supply chains and SCM. They define the supply chain as "a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer" (Mentzer et al., 2001, pp. 4f.). SCM means "the systemic, strategic co-ordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole" (Mentzer et al., 2001, p. 18).

The extant paper conducts a literature review with the principal aim of exploring SCM and logistics issues relevant to bio-energy production systems, considering the need of designing them economically, ecologically and socially sustainably.

3. Methodology – literature review

In this chapter the methodology of the literature review presented in the extant paper is briefly outlined.

"A research literature review is a systematic, explicit, and reproducible design for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners." (Fink, 2005, p. 3) A literature review aims at providing an in-depth account of research conducted in a certain field and thus represents a first step in the theory development process (Meredith, 1993; Mentzer and Kahn, 1995). It may be regarded as an archival research method (Searcy and Mentzer, 2003).

Our process of analysis is structured in the following four steps (Mayring, 2003; cf. also Srivastava, 2007):

a) Defining the unit of analysis: The unit of analysis has been defined as a single research paper.
b) Collecting publications and delimiting the body of literature: Our literature review focuses upon English-speaking peer-reviewed journals, since they are the most common resources for information exchange among researchers. To establish a time span, a starting point was set at 2000. The paper sample was compiled by conducting a literature search based on the combinations of descriptors (1) "biomass" and "bio(–)energy" (both having to be present in the respective paper jointly) as well as (2) "supply chain" or "logistics". These issues had to be found in title, keywords or abstract for a paper being included in the subsequent review. The keyword search was carried out using major databases and library services: Emerald (www.emeraldinsight.com), Springer (www.springerlink.com), Wiley (www.wiley.com), Scopus (www.scopus.com). In total, we identified 54 papers published, dispersed over several journals.
c) Classification context: Assessing the classification context to be adopted in the literature review helps to structure and classify the material. There are two contexts: context 1 refers to a paper's descriptive characteristics; context 2 addresses detailed paper contents at the interface of SCM/logistics and bio-energy.
d) Material evaluation: The material is reviewed and analyzed according to the classification context. Classification context 1 applies pre-defined categories for analyzing main characteristics of the papers as regards journal title, year of publication, regions addressed and research designs applied. Classification context 2 structures issues and challenges of designing and operating biomass chains that secure stable and competitively-priced feedstock supply for bio-energy plants according to (1) the operations harvesting and collection, storage, transport, and pre-treatment techniques as well as (2) the overall supply system design. Conceptualized along the biomass supply chain for energy use, these categories have been derived from the material under examination following an inductive approach, passing through an iterative process of category building, testing and revising by constantly comparing categories and data (Eisenhardt, 1989; Mayring, 2000). Table 1 briefly describes the categories.

Table 1
Issues at the interface of SCM/logistics and bio-energy.

Category	Description
Operations 1–3: Collection/ harvesting, storage, transport	Collecting/harvesting, storing and transporting biomass represent basic operations in the context of bio-energy production.
Operation 4: Pre-treatment techniques	Pre-treatment of biomass seriously impacts economic, environmental and social features of other bio-energy operations such as collecting/harvesting, storing and transporting.
Overall supply system design	System design refers to the challenging task of effectively and efficiently designing and operating bio-energy production.

4. Main characteristics of the analyzed paper sample

Figs. 1 and 2 give an overview over main journals and publication years. Most frequent journals are Biomass and Bioenergy (15 papers), Applied Biochemistry and Biotechnology (8 papers) and Mitigation and Adaption Strategies for Global Change (5 papers). It can be seen that 40 out of 54 papers have been published after the year 2005, while the assessment of 2009 is still incomplete. This indicates that the interface between bio-energy and supply chain/ logistics issues have increased in importance in recent years.

Figs. 3 and 4 present the regions addressed in the papers and the principal research designs applied by the authors. The regions are mainly various European countries, the US and Canada. Other regions such as Asia and Latin America are underrepresented. This shows that the overall research focus is on the industrialized world when evaluating bio-energy production systems. However, the growing globalization of biomass and bio-fuel trade as well as the inter-connectedness of global food, material and energy markets will make it more and more important to strengthen the focus on the developing world (Kaditi, 2009). Research designs applied within the paper sample have been inductively classified into (1) techno-economic assessments, (2) environmental assessments, (3) case studies, (4) focus groups and expert interviews, respectively, and (5) conceptual papers including literature reviews. The analysis shows a clear predominance of data-driven techno-economic assessments – such as multi-criteria assessment models for ranking bio-energy systems (Kumar et al., 2006) – and environmental assessments – such as life cycle inventories for comparing the overall greenhouse gas emissions of biomass and fossil fuel energy systems (Jungmeier and Spitzer, 2001). In contrast, approaches focusing on the management of supply chain relationships and other relevant stakeholder groups take a back seat.

5. Main issues of supply chain management for bio-energy production

The overall purpose of biomass supply chains for energy use is basically twofold: (1) Feedstock costs are to be kept competitive (Hess et al., 2007). (2) Continuous feedstock supply has to be ensured (Sims and Venturi, 2004). In this respect, problems may arise due to growing cycles of most biomass types, unstable natural conditions such as droughts (Mabee et al., 2006), and lacking reliability, willingness, and co-ordination of supply chain actors (Van Belle et al., 2003). In addition, the large volumes of biomass required in bio-energy plants make the biomass sourcing such a crucial and, at the same time, vulnerable activity (Madlener and Bachhiesl, 2007; Perry and Rosillo-Calle, 2008). Fig. 5 depicts how biomass is moving through various main operations along the supply chain for ensuring constant and competitively-priced feedstock supply for energy conversion plants. Main operations are harvesting and collection, storage, transport, and pre-treatment techniques. These operations are coordinated by the design of the overall supply system.

Fig. 6 presents the frequencies of occurrence of the review categories applied for systemizing SCM and logistics issues of bio-energy production. One can see that the overall system design of bio-energy production chains and biomass transport are most relevant issues within the analyzed paper sample, followed by harvesting and collecting biomass. Pre-treatment techniques and storage are less frequently addressed subjects, although found in more than one third of all papers.

The following subchapters systematically present challenges and issues of supply chain and logistics management for bio-energy production, as addressed within the paper sample under examination, along the main categories (1) harvesting and collecting biomass, (2) storage throughout the bio-energy chain, (3) transport in the bio-energy chain, (4) pre-treatment techniques, and (5) design of the bio-energy production system.

5.1. Operation 1: harvesting and collecting biomass

Aspects concerning harvest and collection of biomass for energy use are classified into (1) main options for harvesting/collecting and subsequently processing biomass and (2) characteristics of biomass impacting its harvest, collection, and handling.

5.1.1. Main options for harvesting/collecting and subsequently processing biomass

Options for harvesting forest biomass addressed in the analyzed literature are mechanical logging activities, often conducted as thinning operations (Damen and Faaij, 2006; Mabee et al., 2006; Rauch, 2007). When following a bio-refinery strategy, pre-commercial thinning is of particular interest, since it extracts wood which is of minor use for forest product industries; although it entails additional harvest and transportation costs (Mabee et al., 2006).

Most relevant processing options subsequent to the harvesting of biomass are drying, baling and chipping. It is a common procedure to leave cut trees for a few months at the harvesting site after felling, thus significantly reducing their water content (Yoshioka et al., 2005; Ayoub et al., 2007). Generally, baling and chipping can be done at the harvesting site or at a central gathering point (Hamelinck et al., 2005; Thornley, 2008). Baling is a key technology for forest residues and energy crops like miscanthus, since it increases the density of biomass and makes it easier to handle during logistics operations, while baling reduces simultaneously the risks of deterioration of biomass (Forsberg, 2000; Thornley, 2008). Chipped biomass usually is directly converted thermally or chemically into energy or it is processed to pellets to be transported for longer distances (Hamelinck et al., 2005; Uslu et al., 2008).

Hess et al. (2007) suggest that advances in forestry harvest and collection technologies should be primarily searched for in the key area of conducting selective harvesting, i.e. selecting biomass to be extracted considering both ecological sustainability criteria and the needs of the bio-refinery facility. This is to be done in a minimum-impact mode.

5.1.2. Characteristics of biomass impacting its harvest, collection, and handling

Several papers point to the scattered geographical distribution of biomass resources, particularly forests, over the territory as limiting factor rendering harvest operations costly (e.g. Möller, 2003; Caputo et al., 2005; Gronalt and Rauch, 2007). Fragmented supply areas are a special issue in small and topographically challenged countries like Denmark and Austria, increasing costs and inducing the necessity of careful wood logistics (Madlener and Bachhiesl, 2007; Möller and Nielsen, 2007). Constraints like steep

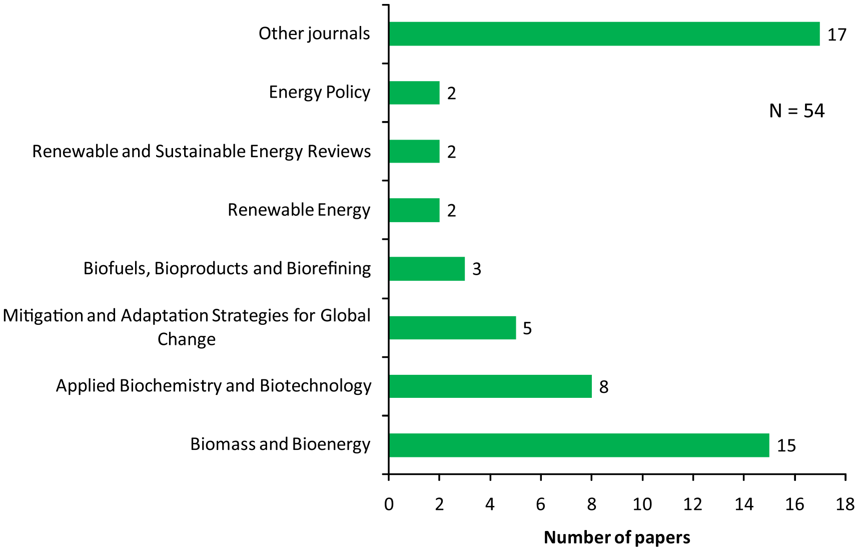

Fig. 1. Distribution of articles over the journals.

slopes or wet soil impact the potential supply volume of wood in a similar manner as the availability of harvesting equipment or labor (Gronalt and Rauch, 2007). In contrast, wood product residues can be collected directly at the wood product industry facilities; similarly, the collection of agricultural residues can rely on existing road infrastructure (Mabee et al., 2006).

One further characteristic of biomass is its limited harvest period induced by the seasonality of most biomass types (Caputo et al., 2005; Madlener and Bachhiesl, 2007). Single annual harvest causes a significant under-utilization of capital-intensive machinery and equipment over the annual cycle, thus increasing the operation costs (Hamelinck et al., 2005; Dunnett et al., 2007; Uslu et al., 2008). In addition, annual harvesting requires in sum more labor in comparison to perennial harvesting (Thornley et al., 2008). Further, a shorter harvest period entails larger inventories, causing storage costs and dry matter losses (Dunnett et al., 2007; Uslu et al., 2008).

Apart from these considerations, harvesting frequency may have an important impact on how different crops are accepted by farmers in developing countries like Tanzania. Here, multi-year crops such as Jatropha, which yield seeds only one to two years after plantation, entail major challenges in terms of financing for poor farmers (Caniëls and Romijn, 2008).

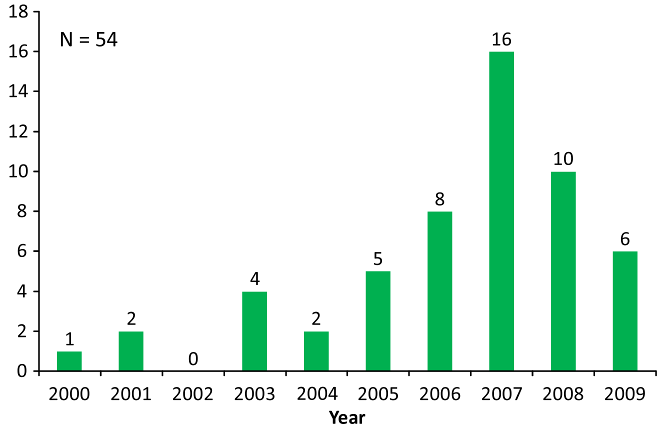

Fig. 2. Distribution of articles over the time period from 2000 to 2009.

5.2. Operation 2: storage throughout the bio-energy chain

Issues of storage addressed in the analyzed paper sample may be organized according to the following three categories: (1) Reasons for storing throughout the biomass chain, (2) costs and risks of storage, and (3) storage options.

5.2.1. Reasons for storing throughout the biomass chain

The principal reason for storage throughout the biomass chain is to adequately match biomass supply and bio-energy plant demand. A short harvesting period of most biomass types and the frequently scattered geographical distribution of biomass over the territory naturally induce the need of storage in order to ensure continual supply of feedstock for bio-energy plants or bio-refineries (Sims and Venturi, 2004; Caputo et al., 2005; Gronalt and Rauch, 2007; Hess et al., 2007; Uslu et al., 2008). Generally speaking, the shorter the harvest season, the higher the number of storage units needed as buffer capacity (Uslu et al., 2008). Thereby storage terminals may be used to supply several plants, if the plants themselves do not have sufficient storage capacity (Gronalt and Rauch, 2007). Closed type warehouses situated adjacent to the bio-energy plant may be used for simultaneously drying the stored biomass (Hamelinck et al., 2005; Thornley, 2008; Gasol et al., 2009), for example by using exhaust heat from the facility (Rentizelas et al., 2009).

5.2.2. Costs and risks of storage

Storage costs mainly hinge on the location and the type of the stores (Van Belle et al., 2003; Caniëls and Romijn, 2008). Moreover, the volume of biomass to be stored and the duration of storage are pivotal cost factors (Van Belle et al., 2003; Ayoub et al., 2007).

Main risks of storage to be minimized by a wise choice of the storage system to be used are (1) biomass quality degradation and (2) dry matter losses of stored biomass. Biological shrinkage diminishes the quality of biomass leading to mass without yield (Hess et al., 2007). Dry matter losses of solid biomass are influenced by the number of storage steps and the storage duration (Sims and Venturi, 2004; Hamelinck et al., 2005; Dunnett et al., 2007; Hess et al., 2007; Rentizelas et al., 2009). Junginger et al. (2008) as well as Damen and Faaij (2006) point to the advantageous characteristics of (wood) pellets in this respect; wood pellets can be stored over a considerable period of time without significant dry

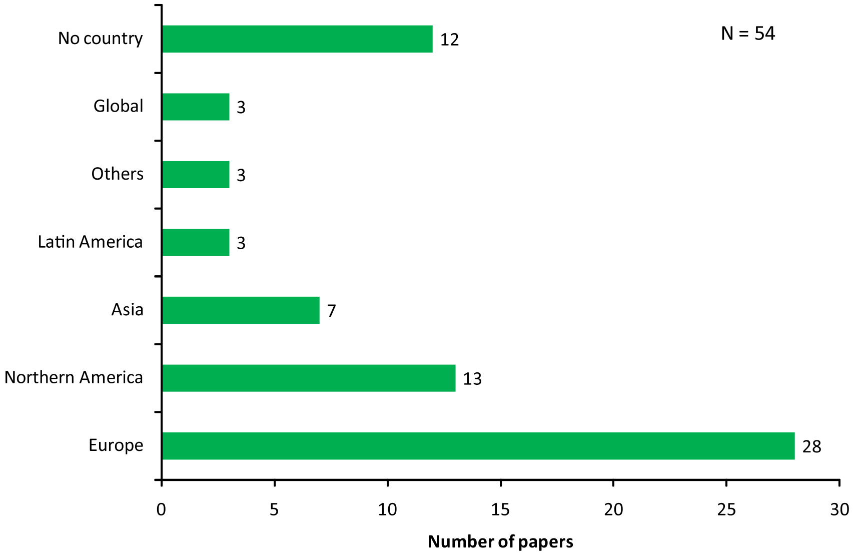

Fig. 3. Regions addressed. Note: Since papers may match none, one, or more than one category, frequencies do not necessarily add up to N = 54.

matter losses. Thornley (2008) suggests in-field storage of miscanthus in order to reduce the emission burden of transports; this, however, inevitably leads to higher losses during storage.

5.2.3. Storage options

Main features of storage options are (1) the location and (2) the type of the storage facility.

(1) Stores may be either located in the direct vicinity to the harvest site, i.e. in the field (Haq and Easterly, 2006; Gasol et al., 2009) and near the forest (Ayoub et al., 2007), respectively, at the roadside (Forsberg, 2000; Hamelinck et al., 2005), or at some further-off hubs, for example in large silos at the harbor (Damen and Faaij, 2006).

(2) Storage types vary from open air to roof covered and air fan (Van Belle et al., 2003). The type of storage mainly depends on the climate and the stage of biomass procession. In this respect, the wet Japanese climate constitutes the need for indoor storage (Ayoub et al., 2007). Similarly, Thornley (2008) assumes covered facilities for storing short rotation coppice willow. While focusing on Greece featuring a Mediterranean climate, also Rentizelas et al. (2009) assume closed type warehouses for storing biomass. When biomass has already been transformed into bales, both open or covered storage may be adequate, since round bales can tolerate exposure to certain levels of rain and weather in general. Square bales, however, being more suitable for stacking, need to be kept in covered storage as they are rather susceptible to weather damage (Haq and Easterly, 2006).

5.3. Operation 3: transport in the bio-energy chain

Transport issues within the bio-energy chain are divided into (1) the legal and infrastructural framework, (2) main variables impacting transport operations, and (3) social and environmental impacts of transport.

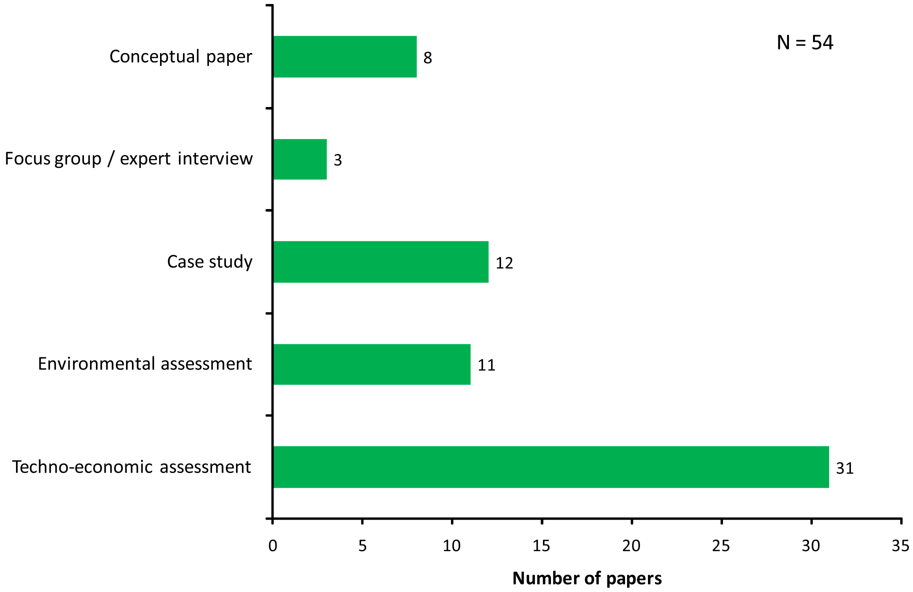

Fig. 4. Research designs. Note: Since papers may match none, one, or more than one category, frequencies do not necessarily add up to N = 54.

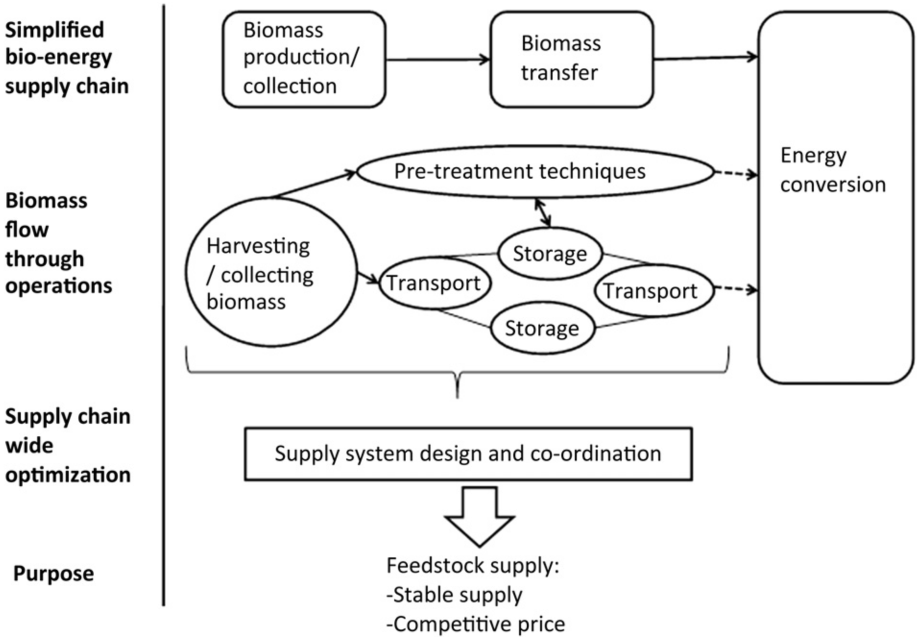
Simplified bio-energy supply chain
Biomass production/ collection
Biomass transfer
Energy conversion
Biomass flow through operations
Pre-treatment techniques
Harvesting / collecting biomass
Storage
Transport
Transport
Storage
Supply chain wide optimization
Supply system design and co-ordination
Purpose
Feedstock supply:
-Stable supply
-Competitive price

Fig. 5. Facilitating biomass flow along the bio-energy chain. Source: Own illustration.

5.3.1. *Legal and infrastructural framework*

The overall legal and infrastructural framework wherein a bio-energy supply system operates constitutes its basic preconditions of functioning. In this respect, Mayfield et al. (2007) highlight the importance of transportation laws. Other authors point to infrastructure (Dunnett et al., 2007; Leduc et al., 2009) and specifically road properties (Möller and Nielsen, 2007). Particularly in developing countries, such as Tanzania, poor infrastructure may represent a severe hurdle for attracting foreign investments into bio-energy systems (Dunnett et al., 2007). In contrast, in the industrialized world other legal and infrastructural features are considered critical; in Austria, for example, transport costs are impacted by the levels of road pricing (Gronalt and Rauch, 2007).

5.3.2. *Main variables impacting transport operations*

The lower energy density of biomass fuels compared to fossil fuels makes transportation a relevant cost factor in bio-energy systems (Mayfield et al., 2007; Searcy et al., 2007; Gasol et al., 2009). One main economic variable of transport is travel time (Gronalt and Rauch, 2007; Möller and Nielsen, 2007; Perpiná et al., 2009; Rentizelas et al., 2009), which is dependent on (1) distance (Hamelinck et al., 2005; Kumar et al., 2006; Gronalt and Rauch, 2007; Thornley et al., 2008; Leduc et al., 2009; Perpiná et al., 2009; Rentizelas et al., 2009) and (2) speed (Möller, 2003; Hamelinck et al., 2005; Möller and Nielsen, 2007):

(1) Distance correlates to the routes travelled (Perpiná et al., 2009) as well as the proportion of tilled land and its biomass yield (Uslu et al., 2008). Actual distance can be minimized by an optimization of routes (Möller and Nielsen, 2007; Hess et al., 2007).
(2) Speed is impacted by road properties and infrastructure (Möller and Nielsen, 2007; Leduc et al., 2009), turtuosity factors of roads (Thornley, 2008; Thornley et al., 2008), mode of transportation (truck, railway, ship, pipeline) (Kumar et al., 2006), and the scheduling of personnel and vehicles (Möller and Nielsen, 2007).

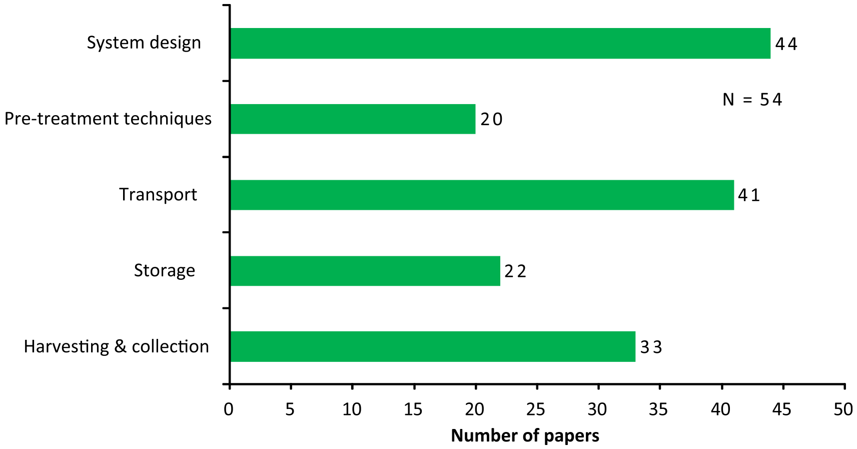

Fig. 6. Frequency analysis of supply chain and logistics issues of bio-energy production. Note: Since papers may match none, one, or more than one category, frequencies do not necessarily add up to N = 54.

Mass (Hamelinck et al., 2005; Searcy et al., 2007) and volume (Hamelinck et al., 2005; Searcy et al., 2007; Thornley, 2008; Leduc et al., 2009) of biomass as well as the capacity of the carriers (Hamelinck et al., 2005; Gronalt and Rauch, 2007) are other key variables of transport. Maximizing truck cycle capacity by increasing the bulk density of biomass (Hess et al., 2007) while optimizing the utilization of vehicle payload (Möller and Nielsen, 2007) are means of reducing transport costs, respective environmental emissions and social burdens. Further relevant variables are labor costs of the truck driver, which are primarily dependent on the travel time, as well as the costs of vehicles and of diesel fuel (Gronalt and Rauch, 2007; Gasol et al., 2009).

5.3.3. *Social and environmental impacts of transport*

Since the locations where biomass is harvested and collected, respectively, and the locations of plants which convert biomass into energy are usually not identical, transport efforts are required, which entail both environmental and social impacts (Kumar et al., 2006; Möller and Nielsen, 2007).

From an environmental point of view, transport emissions are directly linked to transport distances, i.e. to the degree of vicinity of biomass site and conversion plant (Thornley, 2008). However, it should be taken into account that the mode of transport strongly influences emissions. For example, long-distance shipping releases substantially lower CO_2 per unit of length than truck transport (Perry and Rosillo-Calle, 2008). Forsberg (2000) shows that biomass is still beneficial to the environment when transported from Scandinavia to conversion plants in Holland. The study concludes that, provided modern transport modes, bio-energy can be traded over long distances, since the additional emissions of long-distance shipping are of minor importance. Thornley (2008) states that – in comparison to harvesting and tractor operations in the field – lorry transport contributes only little to nitrogen oxides and particulate emissions.

From a societal viewpoint, frequent truck transports inducing traffic congestions may easily provoke resistance of affected communities and citizens. Rail transport reduces the number of loads needed and thus improves the situation, while pipeline transport would minimize these kinds of negative impacts of biomass transportation on the community (Kumar et al., 2006). Note, however, that transporting biomass by pipeline is not compatible with combustion for energy conversion, because the carrier fluid significantly reduces the heating value of the biomass (Searcy et al., 2007).

5.4. *Operation 4: pre-treatment techniques*

Pre-treatment techniques may be analyzed according to (1) the various modes of pre-treatment and according to (2) the purposes and drawbacks, respectively, connected to the utilization of pre-treatment procedures. We define pre-treatment as these techniques that exceed mere mechanical manipulations such as crushing, bundling or grinding.

5.4.1. *Pre-treatment techniques*

Table 2 shows that basically five types of pre-treatment are addressed within our paper sample: Ensiling, drying, pelletization, torrefaction, and pyrolisis. Hereby, drying and pelletization turn out to be the most common of these techniques.

5.4.2. *Purposes and drawbacks of pre-treatment*

Drying reduces the moisture content and thus enhances the degree of efficiency of combustion and gasification processes. Furthermore, drying renders biomass more resistant towards decomposition and fire hazards, while it passes a cost advantage further down the chain, because handling and transport are facilitated by drying-induced weight reductions (Hamelinck et al., 2005). Ambient drying, i.e. drying of biomass in the open air, is a cost-effective procedure, since it does not rely on energy input; however, its effectiveness depends largely on the climate zone and season (Dunnett et al., 2007).

Pelletization reduces the moisture content of biomass and increases its bulk density (Haq and Easterly, 2006; Perry and Rosillo-Calle, 2008; Uslu et al., 2008). Therefore, wood pellets – as one example – hold a rather high heating value (Hamelinck et al., 2005; Junginger et al., 2008). They may directly substitute coal (Damen and Faaij, 2006) and hold higher combustion efficiency in comparison to untreated biomass (Hamelinck et al., 2005; Uslu et al., 2008). Simultaneously, handling and transport suitability is enhanced (Hamelinck et al., 2005; Junginger et al., 2008; Uslu et al., 2008), which has particular effects in the case of longer transport distances (Hamelinck et al., 2005), and respective costs are reduced (Deswarte et al., 2007). Storage times may be prolonged without considerable dry matter losses (Junginger et al., 2008). High costs in comparison to purely mechanical procedures such as baling represent the drawback of pelletization (Haq and Easterly, 2006).

Pelletization is the current state-of-the-art pre-treatment technology. Other more sophisticated technologies – beyond those

Table 2
Various pre-treatment techniques.

Techniques	Definition	References
Ensiling	Ensiling is "the process of creating silage via anaerobic fermentation" (USEPA, n.d.).	Kumar et al., 2006
Drying	Drying reduces the moisture content of biomass (Möller and Nielsen, 2007, p. 292).	Forsberg, 2000; Van Belle et al., 2003; Heaton et al., 2004; Sims and Venturi, 2004; Hamelinck et al., 2005; Yoshioka et al., 2005; Ayoub et al., 2007; Dunnett et al., 2007; Möller and Nielsen, 2007; Thornley, 2008
Pelletization	Pelletization may be described as "drying and pressing of biomass under high pressure to produce cylindrical pieces of compressed and extruded biomass" (Uslu et al., 2008, p. 1210).	Forsberg, 2000; Korhonen and Niutanen, 2003; Hamelinck et al., 2005; Damen and Faaij, 2006; Haq and Easterly, 2006; Deswarte et al., 2007; Junginger et al., 2008; Perry and Rosillo-Calle, 2008; Uslu et al., 2008
Torrefaction	Torrefaction is "a thermal pre-treatment technology performed at atmospheric pressure in the absence of oxygen. Temperatures between 200 and 300 °C are used, which produces a solid uniform product with very low moisture content and a high calorific value compared to fresh biomass" (Uslu et al., 2008, p. 1207).	Uslu et al., 2008
Pyrolisis	Pyrolysis means "the direct thermal decomposition of biomass in the absence of oxygen. Temperatures employed in pyrolysis are 400–800 °C. The products are gas, liquid and solid char, and their relative proportions depend on the pyrolysis method, the characteristics of the biomass and the reaction parameters" (Uslu et al., 2008, p. 1209).	Hamelinck et al., 2005; Uslu et al., 2008

rather simple procedures as ensiling or drying – are torrefaction and pyrolisis. These technologies are still under development, holding unclear economic and technical performance features. In terms of energy efficiency, torrefaction in combination with pelletization and pelletization are clearly more advantageous than pyrolysis (Uslu et al., 2008). Still, Hamelinck et al. (2005) underline that the production of pyrolisis oil via pyrolisis is economically attractive on a small scale; thus pyrolisis represents a technology favorable for local deployment.

5.5. *Design of the bio-energy production system*

Overall design and functioning of the bio-energy systems are core supply chain issues. Most of the papers underline that the whole supply chain – with its interactions and feedback ties – rather than isolated components has to be taken into account for analyzing duly bio-energy production systems. Issues of system design are subdivided into (1) supply chain architecture and (2) tools for enhancing supply chain functioning.

5.5.1. *Supply chain architecture*

It is widely acknowledged throughout the papers under examination that the overall supply chain design has to be optimized (Dunnett et al., 2007; Gronalt and Rauch, 2007). Thereby the optimal locations of various operation sites, such as for chipping or storage, play an outstanding role (Gronalt and Rauch, 2007), as well as the modularity of the different stages within the supply chain. New technologies of modular generators or small expelling units ensure that efficient modern energy production from biomass may also be applied on a decentralized level thus backing local communities (Mayfield et al., 2007; Caniëls and Romijn, 2008).

Bio-energy production systems feature high levels of complexity, involving different market segments and supply chain actors (Elghali et al., 2007), combinations of various biomass resources (wood, agricultural and energy crops, by-products, wastes) (Heaton et al., 2004; Caputo et al., 2005), a number of conversion approaches and end-use applications (Caputo et al., 2005), different harvesting methods, transportation requirements (Ayoub et al., 2007) and operation and handling needs, such as chipping, storing and loading (Gronalt and Rauch, 2007). McCormick and Kåberger (2007) identify energy companies and biomass suppliers as most important actors within bio-energy chains. These two actors are mutually interdependent in a way to cause a dilemma: "Investing in biomass resources is only possible if there are energy companies purchasing biomass, and establishing conversion technologies is only possible if there are biomass suppliers supplying biomass." (McCormick and Kåberger, 2007, p. 450) The feedstock of bio-energy production addressed in the extant paper sample is mainly of agricultural (energy crops, agricultural residues, manure) and silvicultural (forest and wood biomass, short rotation coppice) origin. Industrial residues and municipal organic waste play a subordinate role for bio-energy production (see Fig. 7).

Moreover, bio-energy systems are manifold in size; the scale of production is one decisive parameter for the design of the whole value chain (Elghali et al., 2007). In comparison to fossil fuel power stations, bio-energy plants are generally small in scale; still biomass logistics is a great challenge, since the plants need large amounts of feedstock due to the relatively low calorific value of biomass (Caputo et al., 2005). The lower the overall transportation costs for the required type of feedstock and the more biomass is available per unit area surrounding a plant, the larger the optimum processing plant size (Ghafoori and Flynn, 2007; Searcy et al., 2007). Main incentives for aiming for large-scale biomass procession/conversion projects are (1) the economy of scale of processing (Ghafoori and Flynn, 2007; Searcy et al., 2007) and (2) the opportunity of implementing a multiproduct integrated bio-refinery concept producing high value products while, simultaneously, using the energy of biomass efficiently and thoroughly (Searcy et al., 2007). Such a concept complies with the strong calls for a cascading use of biomass, i.e. producing a material first and then recovering the energy of the resulting waste (UNEP, 2009).

5.5.2. *Tools for enhancing supply chain functioning*

Tools and technologies facilitating and improving, respectively, the functioning of bio-energy supply chains refer to the areas logistics, conversion, biomass cultivation, and management. Logistics is identified as a critical constraining factor of bio-energy supply chain (Caputo et al., 2005; Pessoa et al., 2005; Heaton et al., 2004); hence logistical efficiency is aimed to be enhanced by new software systems and analysis tools (Mayfield et al., 2007). Other studies underline the need of considerably enhancing conversion efficiencies of bio-energy production in order to reduce costs (Heaton et al., 2004; Caputo et al., 2005; Madlener and Bachhiesl,

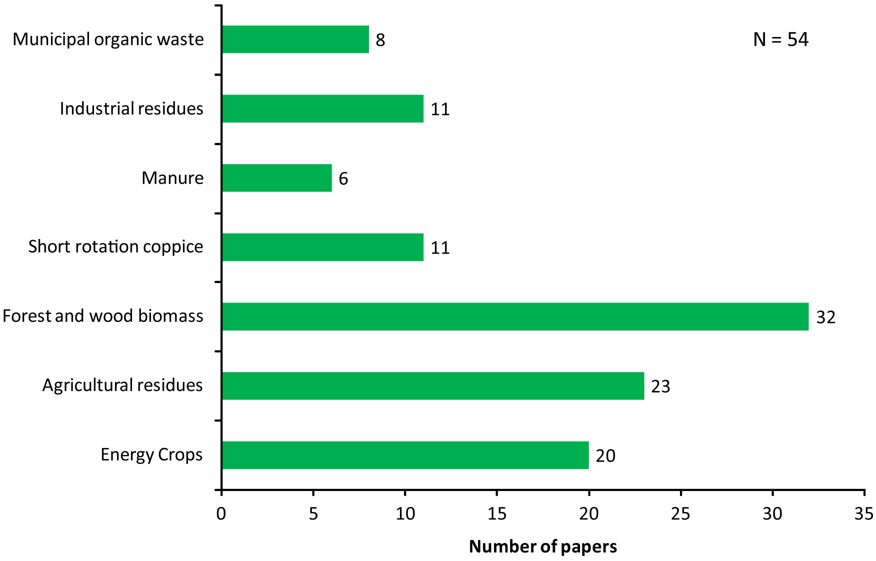

Fig. 7. Feedstock of bio-energy conversion plants. Note: Since papers may match none, one, or more than one category, frequencies do not necessarily add up to N = 54.

2007). Other opportunities for improving bio-energy systems are identified along the line from crop genetics to cultivation techniques and regarding technologies of nutrient recovery (Angelidaki and Ellegaard, 2003; Heaton et al., 2004). Post-treatment of manure digested through biogas production aiming for completely separating the digestate into clean water and nutrients is currently in the testing phase. Removing excess nutrients for sale would offer additional benefits for both farmers and plant operators (Angelidaki and Ellegaard, 2003). Despite the thorough importance of these technological issues, McCormick and Kåberger (2007) consider non-technical challenges rather than technical issues as key barriers affecting bio-energy. Biomass supply may be secured and expanded using innovative management techniques and strategies. For example, new sources of inexpensive biomass for energy production can be tapped by using lignocellulosic material that is not suitable for common forestry and agricultural use (Mabee et al., 2006).

5.6. Summary

Main issues of SCM and logistics for bio-energy production identified by the extant literature review are summarized in Table 3.

6. Discussions

Given the large variety of different bio-energy system designs and, in addition, the rather high flexibility in operating them, a sustainability evaluation necessarily has to look at the specific conditions of the individual bio-energy system under examination, taking the whole system into account comprehending the components biomass resources, supply systems, conversion technologies, and energy services. In addition, sustainability appraisals have to consider the "triple-bottom line", comprising and integrating economic, ecological and social/human aspects of sustainability (Elkington, 1997; Halldórsson et al., 2009). Our literature review shows that SCM and logistics issues are assigned a crucial role for ensuring all three sustainability dimensions of bio-energy systems. This starts when deciding over the basic structure of the bio-energy system (feedstock, supply chain actors, conversion technology) and continues with specific questions of transport, handling, warehousing and storage systems or of pre-treatment procedures of biomass feedstock. Keeping biomass systems profitable and ecologically sustainable requires an elaborate selection of which biomass to collect in which quantities and a well-thought geographical mapping of the collection points and their matching with respective procession sites (Ayoub et al., 2007). Incremental enhancements through organizational and technical learning can continuously improve the integration of the interlocked operations, such as harvesting, handling, and transporting biomass for safeguarding incessant feedstock supply for energy conversion plants (Haq and Easterly, 2006).

Table 3
Summarizing main supply chain and logistics issues.

Harvesting and collection	– Drying, baling, chipping as most relevant post-harvest biomass processing modes – Selective harvesting – Scattered geographical distribution of biomass and topographical constraints – Harvesting period and frequency – Negative environmental impacts of harvest machinery
Storage	– Matching biomass supply (natural growing cycles) and continuous bio-energy plant demands – Risks of storage regarding quality degradation and dry matter losses of biomass – Locations and types of storage facilities
Transport	– Transportation laws and infrastructure – Increasing value density of transported biomass while optimizing the utilization of carrier capacity – Environmental and social impacts of transporting biomass
Pre-treatment	– Drying and pelletization facilitate other operations, decrease deterioration risks, and enhance biomass energy value – Torrefaction and pyrolisis still under development
System design	– Individual adaptation and optimization of system design – High levels of complexities and inter-dependencies of bio-energy production systems – Strategy of cascading use of biomass – Search for technological and managerial innovations for enhancing economic and environmental efficiency and effectiveness while mitigating negative social impacts

Sustainability innovations, such as the establishment of modern bio-energy systems, are often exclusively related to the development, diffusion, and use of novel technologies. It is, however, indispensable to consider organizational and social aspects as well when aiming for overall sustainable development (McCormick and Kåberger, 2005). This is confirmed by our literature sample which point to the tight inter-connectedness of actors in bio-energy chains necessitating their supply-chain-wide co-ordination, relational governance and collaboration in a similar manner as well-designed logistics planning, scheduling and managing are undisputed key capabilities of competitive bio-energy systems. Inter-organizational resources and capabilities emerging from supply-chain-spanning collaboration for ensuring simultaneously economic, environmental and social performance on bio-energy's total life-cycle basis – for example acquired learning capabilities – are prone to become sources of sustained inter-organizational competitive advantage. These resources are particularly difficult to imitate by rivals due to their characteristics of being socially complex, causally ambiguous and historically grown (Gold et al., 2010).

The inter-dependencies even expand beyond the sphere of the economic actors involved in the supply chain to other relevant stakeholders such as regulatory authorities, local communities and the public in general. These stakeholders evaluate bio-energy systems for the better part subjectively according to social impacts, for example noise and visual appearance, food security, or working conditions of employees. Experts, however, still concede these social issues only relatively little importance as assessment criteria for sustainable bio-energy in comparison to economic and ecological criteria (Buchholz et al., 2009). For designing sustainable bio-energy systems, notwithstanding, the interests of all these stakeholders are to be embraced, thus ideally developing among all interest groups commitment to and a common vision of a sustainable energy society while addressing, and, if possible, rebutting social, health and environmental concerns linked to bio-energy production (McCormick and Kåberger, 2005).

In this respect, the role of biomass within the concert of renewable energies has to be defined and should be communicated to all stakeholders. In contrast to current solar and wind energy technologies, bio-energy holds the opportunity to offer an "energy inventory", which may be used for optimizing the power grid by providing peak load services. Research about how to integrate best the various renewable energy technologies (wind, solar, biomass and hydropower installations) in so-called combined power plants has gained momentum in recent years (ISET, 2008). Thus uninterrupted power grid service can be provided even under real-life conditions of oscillating demand without relying on fossil fuels or nuclear power.

7. Conclusions

By means of a mainly inductively derived systematization, this literature review identifies and expounds most relevant issues of

SCM and logistics for bio-energy production. Conceptualized along the bio-energy chain, main review categories are the operations harvesting/collection, storage, transport, and pre-treatment techniques. A further category represents the supply-chain-spanning task of adequately designing and coordinating the overall production system, involving actors, activities, and schedules. These categories as key topics are further (inductively) structured according to sub-categories repeatedly emerging from the material under investigation. Thus this paper presents a review of the academic research field of biomass SCM and logistics for energy use, proposing a rough pattern for analysis and highlighting primary features.

Follow-up research may pick out single items of the extant broad overview, dedicating them a more in-depth examination using empirical investigations or suitable modeling and simulation tools. Moreover, academic research about relationship-focused management aspects of running bio-energy chains – that have been broadly neglected so far – should be strengthened. Empirical analyses may distill challenges and critical success factors of existing bio-energy systems, taking all three facets of sustainability into account while addressing both the whole range of supply chain actors and other relevant stakeholders such as governmental authorities, non-governmental organizations, citizens and communities. Hence, implications and instruments for improving the performance of bio-energy production systems at the triple-bottom line can be formulated and developed, thus ensuring their profitability while maintaining the license to operate within their respective environments by optimizing their ecological and social balance. Suitable theoretical backbone of these analyses is stakeholder theory (Steurer, 2006), the "collaborative paradigm" of SCM (Chen and Paulraj, 2004, p.121) as well as the interlinkage of sustainable SCM, the relational view of strategic management and social network theory (Seuring and Müller, 2008; Gold et al., 2010).

References

Angelidaki, I., Ellegaard, L., 2003. Codigestion of manure and organic wastes in centralized biogas plants – status and future trends. Applied Biochemistry and Biotechnology 109 (1–3), 95–106.

Ayoub, N., Martins, R., Wang, K., Seki, H., Naka, Y., 2007. Two levels decision system for efficient planning and implementation of bioenergy production. Energy Conversion and Management 48 (3), 709–723.

Caputo, A.C., Palumbo, M., Pelagagge, P.M., Scacchia, F., 2005. Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. Biomass and Bioenergy 28 (1), 35–51.

Caniëls, M.C.J., Romijn, H.A., 2008. Supply chain development: insights from strategic niche management. The Learning Organization 15 (4), 336–353.

Damen, K., Faaij, A., 2006. A greenhouse gas balance of two existing international biomass import chains – The case of residue co-firing in a pulverised coal-fired power plant in the Netherlands. Mitigation and Adaptation Strategies for Global Change 11 (5–6), 1023–1050.

Deswarte, F.E.I., Clark, J.H., Wilson, A.J., Hardy, J.J.E., Marriott, R., Chahal, S.P., Jackson, C., Heslop, G., Birkett, M., Bruce, T.J., Whiteley, G., 2007. Toward an integrated straw-based biorefinery. Biofuels, Bioproducts and Biorefining 1 (4), 245–254.

Dunnett, A., Adjiman, C., Shah, N., 2007. Biomass to heat supply chains: applications of process optimization. Process Safety and Environmental Protection 85 (5), 419–429.

Elghali, L., Clift, R., Sinclair, P., Panoutsou, C., Bauen, A., 2007. Developing a sustainability framework for the assessment of bioenergy systems. Energy Policy 35 (12), 6075–6083.

Forsberg, G., 2000. Biomass energy transport: analysis of bioenergy transport chains using life cycle inventory method. Biomass and Bioenergy 19 (1), 17–30.

Gasol, C.M., Martínez, S., Rigola, M., Rieradevall, J., Anton, A., Carrasco, J., Ciria, P., Gabarrell, X., 2009. Feasibility assessment of poplar bioenergy systems in the Southern Europe. Renewable and Sustainable Energy Reviews 13 (4), 801–812.

Ghafoori, E., Flynn, P.C., 2007. Optimizing the logistics of anaerobic digestion of manure. Applied Biochemistry and Biotechnology 137 (1), 625–637.

Gronalt, M., Rauch, P., 2007. Designing a regional forest fuel supply network. Biomass and Bioenergy 31 (6), 393–402.

Hamelinck, C.N., Suurs, R.A.A., Faaij, A.P.C., 2005. International bioenergy transport cost and energy balance. Biomass and Bioenergy 29 (2), 114–134.

Haq, Z., Easterly, J.L., 2006. Agricultural residue availability in the United States. Applied Biochemistry and Biotechnology 129 (1–3), 3–21.

Heaton, E.A., Clifton-Brown, J., Voigt, T.B., Jones, M.B., Long, S.P., 2004. Miscanthus for renewable energy generation: European Union experience and projections for Illinois. Mitigation and Adaptation Strategies for Global Change 9 (4), 433–451.

Hess, J.R., Wright, C.T., Kenney, K.L., 2007. Cellulosic biomass feedstocks and logistics for ethanol production. Biofuels, Bioproducts and Biorefining 1 (3), 181–190.

Junginger, M., Bolkesjø, T., Bradley, D., Dolzand, P., Faaija, A., Heinimö, J., Hektor, B., Leistad, Ø., Ling, E., Perry, M., Piacente, E., Rosillo-Calle, F., Ryckmans, Y., Schouwenberg, P.P., Solberg, B., Trømborg, E., da Silva Walter, A., de Wit, M., 2008. Developments in international bioenergy trade. Biomass and Bioenergy 32 (8), 717–729.

Jungmeier, G., Spitzer, J., 2001. Greenhouse gas emissions of bioenergy from agriculture compared to fossil energy for heat and electricity supply. Nutrient Cycling in Agroecosystems 60 (1–3), 267–273.

Korhonen, J., Niutanen, V., 2003. Material and energy flows of a local forest industry system in Finland. Sustainable Development 11 (3), 121–132.

Kumar, A., Sokhansanj, S., Flynn, P.C., 2006. Development of a multicriteria assessment model for ranking biomass feedstock collection and transportation systems. Applied Biochemistry and Biotechnology 129 (1–3), 71–87.

Leduc, S., Schmid, E., Obersteiner, M., Riahi, K., 2009. Methanol production by gasification using a geographically explicit model. Biomass and Bioenergy 33 (5), 745–751.

Mabee, W.E., Fraser, E.D.G., McFarlane, P.N., Saddler, J.N., 2006. Canadian biomass reserves for biorefining. Applied Biochemistry and Biotechnology 129 (1–3), 22–40.

Madlener, R., Bachhiesl, M., 2007. Socio-economic drivers of large urban biomass cogeneration: sustainable energy supply for Austria's capital Vienna. Energy Policy 35 (2), 1075–1087.

Mayfield, C.A., Foster, C.D., Smith, C.T., Gan, J., Fox, S., 2007. Opportunities, barriers, and strategies for forest bioenergy and bio-based product development in the Southern United States. Biomass and Bioenergy 31 (9), 631–637.

McCormick, K., Kåberger, T., 2007. Key barriers for bioenergy in Europe: economic conditions, know-how and institutional capacity, and supply chain co-ordination. Biomass and Bioenergy 31 (7), 443–452.

Möller, B., 2003. Least-cost allocation strategies for wood fuel supply for distributed generation in Denmark – A geographical study. International Journal of Sustainable Energy 23 (4), 187–197.

Möller, B., Nielsen, P.S., 2007. Analysing transport costs of Danish forest wood chip resources by means of continuous cost surfaces. Biomass and Bioenergy 31 (5), 291–298.

Perpiná, C., Alfonso, D., Pérez-Navarro, A., Penalvo, E., Vargas, C., Cárdenas, R., 2009. Methodology based on Geographic Information Systems for biomass logistics and transport optimization. Renewable Energy 34 (3), 555–565.

Perry, M., Rosillo-Calle, F., 2008. Recent trends and future opportunities in UK bioenergy: maximising biomass penetration in a centralised energy system. Biomass and Bioenergy 32 (8), 688–701.

Pessoa Jr., A., Roberto, I.C., Menossi, M., dos Santos, R.R., Filho, S.O., Penna, T.C.V., 2005. Perspectives on bioenergy and Biotechnology in Brazil. Applied Biochemistry and Biotechnology 121 (1–3), 59–70.

Rauch, P., 2007. SWOT analyses and SWOT strategy formulation for forest owner cooperations in Austria. European Journal of Forest Research 126 (3), 413–420.

Rentizelas, A.A., Tatsiopoulos, I.P., Tolis, A., 2009. An optimization model for multi-biomass tri-generation energy supply. Biomass and Bioenergy 33 (2), 223–233.

Searcy, E., Flynn, P., Ghafoori, E., Kumar, A., 2007. The relative cost of biomass energy transport. Applied Biochemistry and Biotechnology 137–140 (1–12), 639–659.

Sims, R.E.H., Venturi, P., 2004. All-year-round harvesting of short rotation coppice eucalyptus compared with the delivered costs of biomass from more conventional short season, harvesting systems. Biomass and Bioenergy 26 (1), 27–37.

Thornley, P., 2008. Airborne emissions from biomass based power generation systems. Environmental Research Letters 3 (1), 1–6.

Thornley, P., Rogers, J., Huang, Y., 2008. Quantification of employment from biomass power plants. Renewable Energy 33 (8), 1922–1927.

Uslu, A., Faaij, A.P.C., Bergman, P.C.A., 2008. Pre-treatment technologies, and their effect on international bioenergy supply chain logistics. Techno-economic evaluation of torrefaction, fast pyrolysis and pelletisation. Energy 33 (8), 1206–1223.

Van Belle, J.F., Temmerman, M., Schenkel, Y., 2003. Three level procurement of forest residues for power plant. Biomass and Bioenergy 24 (4), 401–409.

Yoshioka, T., Aruga, K., Nitami, T., Kobayashi, H., Sakai, H., 2005. Energy and carbon dioxide (CO_2) balance of logging residues as alternative energy resources: system analysis based on the method of a life cycle inventory (LCI) analysis. Journal of Forest Research 10 (2), 125–134.

Further readings

Abraham, E.R., Ramachandran, S., Ramalingam, V., 2007. Biogas: can it be an important source of energy? Environmental Science and Pollution Research 14 (1), 67–71.

Allen, J., Browne, M., Hunter, A., Boyd, J., Palmer, H., 1998. Logistics management and costs of biomass fuel supply. International Journal of Physical Distribution & Logistics Management 28 (6), 463–477.

Azar, C., Lindgren, K., Larson, E., Möllersten, K., 2006. Carbon capture and storage from fossil fuels and biomass – costs and potential role in stabilizing the atmosphere. Climatic Change 74 (1–3), 47–79.

von Blottnitz, H., Curran, M.A., 2007. A review of assessments conducted on bioethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. Journal of Cleaner Production 15 (7), 607–619.

Buchholz, T., Luzadis, V.A., Volk, T.A., 2009. Sustainability criteria for bioenergy systems: results from an expert survey. Journal of Cleaner Production 17 (Suppl. 1), S86–S98.

Chen, I.J., Paulraj, A., 2004. Towards a theory of supply chain management: the constructs and measurements. Journal of Operations Management 22 (2), 119–150.

CSCMP (Council of Supply Chain Management Professionals) (Ed.), n.d. CSCMP Supply Chain Management Definitions [Online]. Available at: http://cscmp.org/aboutcscmp/definitions.asp (accessed 04.05.09).

Dyllick, T., Hockerts, K., 2002. Beyond the business case for corporate sustainability. Business Strategy and the Environment 11 (2), 130–141.

Ecosense (Ed.), 2007. Klimafaktor Biokraftstoff. Experten zur Nachhaltigkeitszertifizierung [Bioenergy and its Impact on the Climate: Experts Discuss Certification Ensuring Sustainability Criteria]. Schriftenreihe zu Nachhaltigkeit und CSR, vol. 1.

Eisenhardt, K.M., 1989. Building theories from case study research. Academy of Management Review 14 (4), 532–550.

Elkington, J., 1997. Cannibals with Forks: The Triple Bottom Line of 21st Century Business. Capstone, Oxford.

Fink, A., 2005. Conducting Research Literature Reviews: From the Internet to Paper. Sage, Thousand Oaks.

Gerbens-Leenes, W., Hoekstra, A.Y., van der Meer, T.H., 2009. The water footprint of bioenergy. Proceedings of the National Academy of Sciences (PNAS) 106 (25), 10219–10223.

Gold, S., Seuring, S., Beske, P., 2010. Sustainable supply chain management and inter-organisational resources: a literature review. Corporate Social Responsibility and Environmental Management 17 (4), 230–245.

GTZ (German Technical Cooperation) (Ed.), 2006. Kraftstoffe aus nachwachsenden Rohstoffen – Globale Potenziale und Implikationen für eine nachhaltige Landwirtschaft und Energieversorgung im 21. Jahrhundert [Fuels from renewable resources – Global potentials and implications for sustainable agriculture and energy supply in the 21st century], Berlin.

Gustavsson, L., Madlener, R., Hoen, H.F., Jungmeier, G., Karjalainen, T., Klöhn, S., Mahapatra, K., Pohjola, J., Solberg, B., Spelter, H., 2006. The role of wood material for greenhouse gas mitigation. Mitigation and Adaptation Strategies for Global Change 11 (5–6), 1097–1127.

Halldórsson, Á., Kotzab, H., Skjøtt-Larsen, T., 2009. Supply chain management on the crossroad to sustainability: a blessing or a curse? Logistics Research 1 (2), 83–94.

Heinimö, J., Ojanen, V., Kass, T., 2008. Views on the international market for energy biomass in 2020: results from a scenario study. International Journal of Energy Sector Management 2 (4), 547–569.

ISET (Fraunhofer Institute for Wind Energy and Energy System Technology) (Ed.), 2008. Das regenerative Kombikraftwerk [The renewable combined power plant]. Final report, 31 April 2008. Available at: http://www.kombikraftwerk.de/fileadmin/downloads/2008_03_31_Ma__KombiKW_Abschlussbericht.pdf (accessed 26.01.10).

Kadda, A.S., Venus, A.M., Lataza, D.B., Solis, M.R.E., 2008. Operational effectiveness of centralized nursery for small-scale forestry in San CarlosCity, Negros Occidental, the Philippines: lessons learned in seedling production for commercial energy crop plantations. Small-Scale Forestry 7 (3–4), 319–331.

Kaditi, E.A., 2009. Bio-energy policies in a global context. Journal of Cleaner Production 17 (Suppl. 1), S4–S8.

Kerckow, B., 2007. Competition between agricultural and renewable energy production. Quarterly Journal of International Agriculture 46 (4), 333–347.

Londo, M., Deurwaarder, E., 2007. Developments in EU biofuels policy related to sustainability issues: overview and outlook. Biofuels, Bioproducts and Biorefining 1 (4), 292–302.

Mabee, W.E., Gregg, D.J., Saddler, J.N., 2005. Assessing the emerging biorefinery sector in Canada. Applied Biochemistry and Biotechnology 123 (1–3), 765–778.

Mayring, P., 2000. Qualitative content analysis [28 paragraphs]. Forum Qualitative Sozialforschung/Forum Qualitative Social Research 1 (2) [Online Journal]. Available at: http://qualitative-research.net/fqs/fqs-e/2-00inhalt-e.htm (accessed 24.04.09).

Mayring, P., 2003. Qualitative Inhaltanalyse – Grundlagen und Techniken (Qualitative Content Analysis – Basics and Techniques). Beltz Verlag, Weinheim.

McCormick, K., Kåberger, T., 2005. Exploring a pioneering bioenergy system: the case of Enköping in Sweden. Journal of Cleaner Production 13 (5), 1003–1014.

Mentzer, J.T., Kahn, K.B., 1995. A framework of logistics research. Journal of Business Logistics 16 (1), 231–251.

Mentzer, J.T., DeWitt, W., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D., Zacharia, Z.G., 2001. Defining supply chain management. Journal of Business Logistics 22 (2), 1–25.

Meredith, J., 1993. Theory building through conceptual methods. International Journal of Operations & Production Management 13 (5), 3–11.

Möllersten, K., Gao, L., Yan, J., 2006. CO_2 capture in pulp and paper mills: CO_2 balances. Mitigation and Adaptation Strategies for Global Change 11 (5–6), 1129–1150.

Nguyen, T.L.T., Gheewala, S.H., Sagisaka, M., 2010. Greenhouse gas savings potential of sugar cane bio-energy systems. Journal of Cleaner Production 18 (5), 412–418.

Owens, G.M., 2007. Analyzing impacts of bioenergy expansion in China using strategic environmental assessment. Management of Environmental Quality: An International Journal 18 (4), 396–412.

Paiva, R.P.O., Morabito, R., 2009. An optimization model for the aggregate production planning of a Brazilian sugar and ethanol milling company. Annals of Operations Research 169 (1), 117–130.

Puppan, D., 2002. Environmental evaluation of biofuels. Periodica Polytechnica Ser. Soc. Man. Sci. 10 (1), 95–116.

Puy, N., Tàbara, D., Molins, J.B., Almera, J.B., Rieradevall, J., 2008. Integrated Assessment of forest bioenergy systems in Mediterranean basin areas: the case of Catalonia and the use of participatory IA-focus groups. Renewable and Sustainable Energy Reviews 12 (5), 1451–1464.

Recchia, L., Daou, M., Rimediotti, M., Cini, E., Vieri, M., 2009. New shredding machine for recycling pruning residuals. Biomass and Bioenergy 33 (1), 149–154.

Reijnders, L., Huijbregts, M.A.J., 2008. Palm oil and the emission of carbon-based greenhouse gases. Journal of Cleaner Production 16 (4), 477–482.

Reinhard, J., Zah, R., 2009. Global environmental consequences of increased biodiesel consumption in Switzerland: consequential life cycle assessment. Journal of Cleaner Production 17 (Suppl. 1), S46–S56.

Searcy, D.L., Mentzer, J.T., 2003. A framework for conducting and evaluating research. Journal of Accounting Literature 22, 130–167.

Seuring, S., Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production 16 (15), 1699–1710.

Srivastava, S.K., 2007. Green supply-chain management: a state-of-the-art literature review. International Journal of Management Reviews 9 (1), 53–80.

Steurer, A., 2006. Mapping stakeholder theory Anew: from the ‘Stakeholder theory of the Firm’ to three perspectives on business-society Relations. Business Strategy and the Environment 15 (1), 55–69.

UNEP (United Nations Environment Programme) (Ed.), 2009. Towards Sustainable Production and Use of Resources: Assessing Biofuels.

USEPA (United States Environmental Protection Agency) (Ed.), n.d. Crop Glossary. Available at: http://www.epa.gov/oecaagct/ag101/cropglossary.html (accessed 10.10.09.).

Van der Horst, D., 2008. Social enterprise and renewable energy – emerging initiatives and communities of practice. Social Enterprise Journal 4 (3), 171–185.

WBGU (German Advisory Council on Global Change) (Ed.), 2009. World in Transition – Future Bioenergy and Sustainable Land Use. Earthscan, London.

WCED (World Commission on Environment and Development) (Ed.), 1987. Our Common Future. Oxford University Press, Oxford.

Woods, J., Hemstock, S., Burnyeat, W., 2006. Bio-energy systems at the community level in the South Pacific: impacts & monitoring. Mitigation and Adaptation Strategies for Global Change 11 (2), 469–500.

Yamamoto, H., Fujino, J., Yamaji, K., 2001. Evaluation of bioenergy potential with a multi-regional global-land-use-and-energy model. Biomass and Bioenergy 21 (3), 185–203.